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Effect of Chemical Activating Agents on Surface Area and Methylene Blue Uptake Capacity of Activated Carbons

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Abstract. Activated carbon from *Acacia asak* (Fabaceae) tree branches was prepared utilizing three-steps-process and H_3PO_4, $ZnCl_2$, H_2SO_4, K_2CO_3, NaOH and KOH as chemical activating agents. In addition to the elemental analysis of precursor materials, produced activated carbon (ATB-AC) was also analyzed for moisture content, ash content, pH value, bulk density, volatile matter, hardness, specific surface area (S_{BET}), iodine number and pore volume. Results revealed that the quality of ATB-AC is well comparable to the available commercial activated carbon (CAC). The S_{BET} was found to be in the order of ATB-AC1> ATB-AC2> ATB-AC4> ATB-AC6> ATB-AC3> ATB-AC5. All the produced ATB-AC demonstrated good MB (methylene blue) removal efficiency, whereas ATB-AC1 and ATB-AC2 (produced from H_3PO_4, and $ZnCl_2$) showed higher efficiency. It is concluded that the chemical activating agent has significant effect on produced AC keeping all other production parameters constant. Among the six studied chemicals, H_3PO_4 and $ZnCl_2$ produced AC exhibited high S_{BET} surface area and MB uptake capacity.

Keywords: activated carbon, activating agent, characterization, *Acacia asak*, S_{BET} surface area, MB uptake capacity.

Introduction

Saudi Arabia has one of the largest industrial setup in the world including petroleum refineries and various units, manufacturing industrial and other commercial products (JC, 2016). These industries during production process generate huge amount of wastewater and require treatment before discharge to the environment or re-use. Growing concern on the increasing environmental pollution due to discharge of wastewater necessitates the treatment of wastewater up to the allowable limits for discharge or re-use (Danish and Ahmad, 2018). Various wastewater treatment processes have been developed to meet the strict pollution control legislations. Activated carbon (AC) is one of the robust tool to remove the pollutants from wastewater streams due to availability of high adsorbing surface area (Özsin *et al*., 2019). As reported in literature large quantity of AC is being used in Saudi Arabia and most of it is imported to meet the requirements of AC. About 6.5 metric tonnes of AC was imported during 1995 to 2002 (Essa *et al*., 2004). The annual expenditure exceeds $3.2 million for importing AC to meet the growing demand (Saleem *et al*., 2017).

Large surface area and physico-chemical properties of AC allows to preferentially adsorb organic materials and other polar and non polar compounds from gas or liquid streams (Wang *et al*., 2012). Commercial AC are expensive, which limits the use of this excellent adsorbent (Lin and Wang, 2017). Stringent environmental legislations and environmental control policies demand huge quantities of AC having appropriate characteristics for each particular application. In order to solve this problem researchers utilized varieties of waste material to get economical AC possessing appropriate characteristics such as high BET surface area (S_{BET}) and pollutant uptake capacity (Sartova *et al*., 2019). In general, an AC must have adequate adsorptive capacity, low ash content, mechanical strength and low production cost.

Preparation of activated carbon. Theoretically, AC can be produced by utilizing any material rich in carbonaceous material. Researchers tried varieties of material to get AC having high surface area and pollutant uptake capacity utilizing low cost precursor material (Ramirez *et al*., 2017).

Precursor materials utilized in the past. Literature shows that researchers utilized variety of materials including *Moringa oleifera* seeds (Warhurst *et al*., 1997), apricot (Erdoðan *et al*., 2005), corn cobs (Cao *et al*., 2006), date stones (Haimour and Emeish, 2006), cherry stones (Olivares-Marín *et al*., 2006), waste tea (Amarasinghe and Williams, 2007), cotton stalk (El-Hendawy *et al*., 2008), olive stoves (Kula *et al*., 2008), olive cake (Baccar *et al*., 2009), bamboo (Liu *et al*.,

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2010), almond shells (Plaza *et al*., 2010), giant seeds (Yue *et al*., 2010), coconut shell (Cazetta *et al*., 2011), *Acacia mangium* (Danish *et al*., 2013), date palm fronds (Ahmad *et al*., 2015), *Acacia etbaica* (Gebrekidan *et al*., 2015), olive stones (Yakout and El Deen, 2016), wood waste (Ramirez *et al*., 2017), waste tea (Zhou *et al*., 2018). More recently studies has been done on wine making wastes (Alcaraz *et al*., 2018), chickpea waste (Özsin *et al*., 2019), cotton processing wastes (Sartova *et al*., 2019), olive branches (Alkherraz *et al*., 2020), rice husks (Menya *et al*., 2020), Indonesian Mangrove (Budianto *et al*., 2019), etc. Reduction in the produced AC cost was the prime objective of most of the studies. The use of waste materials as low-cost adsorbents is a feasible option due to their contribution in reduction of waste disposal cost and pollution load on the environment (Sartova *et al*., 2019; Zhou *et al*., 2018; Ramirez *et al*., 2017). Production of AC required some physical and chemical activation treatment in addition to thermal treatment. Generally, AC production methods are proprietary and commercial in nature (Wong *et al*., 2018).

Production methods utilized in the past. Mohanty *et al*. (2005) produced AC by using *Terminalia arjuna* nuts as raw material in a $ZnCl_2$ chemical activation method. When using a 300% ($ZnCl_2$/ waste) at 500°C carbonization temperature and a duration of 1 h, the resulting S_{BET} was 1260 m^2/g. Tsai *et al*. (2001) used corn cobs (as a carbonaceous material) and zinc chloride (as an activation agent) to produce activated carbon. The impregnation ratio, i.e., the $ZnCl_2$/cob ratio and the activation temperature were noted as the most important factors. Ahmadpour *et al*. (1998) produced AC by using macadamia nutshell precursors along with KOH and $ZnCl_2$ as the chemical activation agents. Qiao *et al*. (1997) report the use of pitch resulting from ethylene tar oil to produce activated carbon with high specific surface areas (approx. 2600 to 3600 m^2/g) that showed a significant adsorption tendency for benzene. Chemical activation was initiated by using KOH.

Several other surface properties of the locally produced activated carbon samples were also studied and reported. Cox *et al*. (1999) produced activated carbon by employing flax shive as the raw material and H_2SO_4 as activating agent. The authors studied several variables such as the sulfuric acid solution strength and amount, temperature and time allowed for the reaction to proceed. Salame and Bandosz (2000) prepared activated carbon with wood. The activation agents were phosphoric acid and potassium hydroxide. The phosphoric acid activation produced activated carbon with a lower specific surface area compared with that from the potassium hydroxide activation (which produced activated carbon of upto 2300 m^2/g specific surface area).

Lukman *et al*. (2013) reported the use of date palm tree branches for the production of AC with a high specific surface area and a high mesopore area. The optimum AC production conditions were found to be H_3PO_4 = 40% (w/w) furnace hold temperature (T) = 700°C, impregnation ratio (R) = 2 (v-acid/w-CB) and furnace hold time (t) = 1 h. The AC sample that was produced by using the above mentioned chemical activation procedure and specific conditions exhibited an S_{BET} (BET specific surface area) value of 1224 m^2/g, which was comparable to that of some widely used commercial AC samples. Additionally, the above mentioned AC sample also successfully removed *p*-cresol from a synthetic industrial wastewater sample. Furthermore, the activated carbon samples produced at 500 and 700°C showed good adsorption capacity.

Production of AC could be done by utilizing physical or chemical methods. Conveniently, AC can be produced in one or two steps. In a single step process carbonization and activation done simultaneously in a single step heating with an activation agent (Kalderis *et al*., 2008). In two step process first carbonization of precursor material performed in an inert atmosphere at a temperature range of 400°C to 800°C (Üner and Byrak, 2018; Chowdhury *et al*., 2013). In the second step activation of carbon done either by physical activation method utilizing steam, carbon dioxide or nitrogen (Alayan *et al*., 2019; Lua and Yang, 2005) or chemical activation processes utilizing an acid or a base (Herawan *et al*., 2013). Conventionally, activation temperature utilized is ranging from 800 to 1000 °C (Guo and Lua, 2000).

Recently, it is reported that utilization of a three-steps-process produced high quality AC. Tran *et al*., (2017) prepared AC from *Cassra fistula* (Golden shower) in which hydrothermal carbonization process followed by pyrolysis process to form biochar. In the third step, obtained biochar was activated chemically utilizing potassium carbonate (K_2CO_3) to produce AC having better adsorption performance for cationic dye than AC produced by single or two step processes (Tran *et al*., 2017). Studies shows that three-step synthesis is more effective approach for AC production (Wong *et al*., 2018). Studies reported in literature showing the AC produced by three-steps-process yield highest adsorption

capacity which indicating importance of three-steps-process for production of good quality AC (Abdel-Khalek *et al*., 2017;Singh *et al*., 2017). Therefore, in the present study a three-steps-process utilized to produce AC having high S_{BET} surface area (Okman *et al*., 2014; Sun *et al*., 2010; Hayashi *et al*., 2000).

Rationale of utilizing chemical activation agents. In the chemical activation process, a carbonaceous material undergoes degradation and dehydration process with activating agents such as an acid or a base (Nor *et al*., 2013). Chemical activation generally done at low temperatures and shorter activation time than physical activation. (Nor *et al*., 2013; Guo and Lua, 2000). Therefore, process provides cost effective method for AC production by utilizing less energy and provide high S_{BET} surface area and better yield (Herawan *et al*., 2013; Guo and Lua, 2000). Researchers utilized variety of activating agents, such as H_3PO_4 (Kalderis *et al*., 2008) $ZnCl_2$ (Moreno-Pirajan and Giraldo, 2010), KOH (Romanos *et al*., 2011), H_2SO_4 (Jawad *et al*., 2016) and phytic acid, ($C_6H_{18}O_{24}P_6$) (Cheng *et al*., 2016).

Although there were extensive researches in the past addressing the production and characterization of AC from various carbonaceous materials, yet there is limited information available about the use of *Acacia asak* tree branches (ATB) as a raw material. Production of activated carbon from ATB provides two fold benefits, acquiring a low cost AC from waste material generated during pruning of trees and reduction in the environmental pollution due to decay and disposal of this material (Shivayogimath *et al*., 2014).

Studies in the past revealed that AC was produced from different precursor materials and utilizing various activating agents. In addition to that, different production techniques and experimental conditions were utilized. Therefore, it is not possible to compare the performance of these ACs with each other and direct comparison of performance of such ACs in term of removal efficiency and adsorption capacity is meaningless. Present study is a step towards providing comparison between six different AC produced by three-steps-process utilizing six different activating agents and evaluate their properties to remove MB dye from wastewater effluent.

Material and Methods

Present study is aimed to utilize *Acacia asak* tree branches (ATB) to produce AC by three-steps-process. In order to compare the ability of six most commonly used chemical activating agents; H_3PO_4, $ZnCl_2$, H_2SO_4, K_2CO_3, NaOH and KOH were used. Therefore, study is divided in three phases including (1) producing ATB-AC utilizing three-steps-process, while using six above mentioned chemical activating agents. (2) characterizing the ATB-AC and (3) comparing the MB dye removal efficiency and adsorptive capacity of all ACs with the commercially available AC (Filtrasorb® -400) available with Calgon Carbon Corporation.

Preparation of ATB-AC. *Acacia asak* tree branches collected from Jubal Industrial city. After washing with hot distilled water and drying, branches were cut into small pieces and dried in Blast Air Drying Oven (DHG-9030A, China) at 110 ±5 °C for 48 h. Dried material was cut into 0.4 to 0.5 mm size particles utilizing variable speed Universal Cutting Mill (PULVERISETTE 19). Prepared granular material divided into six test samples and each sample passed through three-steps-process utilizing six activating agents H_3PO_4, $ZnCl_2$, H_2SO_4, K_2CO_3, NaOH and KOH to obtain ATB-AC1, ATB-AC2, ATB-AC3, ATB-AC4, ATB-AC5 and ATB-AC6 respectively.

The prepared granular material was mixed with 50% V/V distilled water and hydrothermal carbonization process applied to the material for 24 h at 200±5 °C in a sealed container. Steam produced in sealed container provide an extra pressure on the material and providing additional driving force for hydrochar production. Later produced hydrochar was mixed with 40% V/V activating agent and slurry was left idle for 12 h. In the last step, produced material was placed in Muffle Furness for 12 h at 600 ±5 °C to obtain final product. After that, the produce AC was cooled to room temperature and washed with 0.2% NaOH solution (for ATB-AC1, ATB-AC2 and ATB-AC3) and 0.2% HCl solution (for ATB-AC4, ATB-AC5 and ATB-AC6). Finally, produced AC is washed with distilled water to obtain AC having pH near neutral value.

In order to assess the properties of produced AC, characterization of produced AC was performed and discussed in the following section.

Characterization of ATB material and produced ACs. Characterization of produced ACs was done by following the standard procedures mentioned in the literature (Schaeffer, 2002). Bulk density was determined by standard ASTM D2395 method, moisture content by ASTM D4933-99, 201, fixed carbon by ASTM D3172; ISO 1350, volatile matter by ASTM D5832-

98, hardness determined by Ball-Pan Hardness test using ASTM D3802 method, ash content by ASTM D2866-94, 2004, iodine number by ASTM D4607-94. The BET surface area (S_{BET}) and pore volume were determined by utilizing the amount of N2 held at $P/\mathring{P}$ = 0.98 reaching equilibrium. The S_{BET} surface area determined by Quantachrome Nova-2200e series instrument. Pore mean radius (R) is calculated from values of pore volume (Vp) and BET surface area (S_{BET}) utilizing the empirical relationship (Haul,1982).

$$R = 2Vp/S_{BET} \quad \text{..... (1)}$$

In order to determine the elemental composition of precursor material ATB, the PerkinElmer® 2400 Series II CHNS/O Elemental Analyzer was used. The proximate analysis was performed by utilizing TGA 4000 System, with a compact ceramic furnace following the standard ASTM procedures. Hardness was determined by utilizing Gilson SS-30 Ro-Tap Sieve Shaker.

Efficiency of ATB-AC for methylene blue dye removal from industrial wastewater. Colouring dyes are the prime contaminant of wastewater generated in textile, paper, paints and plastics industries (Yaseen and Scholz, 2019). It is reported that textile industries using more than 3600 types of coloring dyes (pure earth and green cross Switzerland, 2017). A significant amount of such dyes are discharged into the water bodies (Wong *et al*., 2018; Ahmed *et al*., 2012). These dyes are not only harmful for aquatic animals such as fishes, also having negative effects on aquatic plants. Some of these dyes even comes under the priority pollutants list due to their mutagenicity and carcinogenicity (Kalita *et al*., 2017). Most of these dyes having very little removal during conventional wastewater treatments or even resistant against treatment (Regtiet *et al*., 2017). Methylene blue (MB) is one of the stuborn dye having severe to mild health effects including skin, eyes and brain related effects (Ardekani, 2017). Thus, large number of investigations for MB removal from industrial effluents are reported in the literature (Wong *et al*., 2018). In the present study synthetic wastewater containing MB dye used to test the produced ACs and determine their removal efficiency (Saleem *et al*., 2017; Shah *et al*., 2015).

Seven sets of 100 mL stopper flasks containing 10 g of ACs (produced six types of ACs and CAC, Filtrasorb® -400) were filled with 100 mL of solution having concentration of 50 mg/L MB dye. Prepared flasks were placed in a speed adjustable orbital shaker (Model, NB-10) at 300 rpm and allowed to equilibrate for 48 h (Saleem *et al*., 2010). Later, 20 mL samples from each flask were filtered through 0.45 μm filter (Millipore), and analyzed for residual concentrations of MB dye using the UV-spectrophotometer Shimadzu UV-1301PC at 644 nm wavelength. A calibration curve between absorbance and MB concentration was prepared by using MB standard solutions having concentrations from 10 to 60 mg/L.

Results and Discussion

In the present experimental study six ACs were characterized and their properties were also compared. Results obtained in the present study are discussed in the following sections.

Production and characterization of AC. A comparison for the composition of ATB with other species of *Acacia* tree branches are presented in Table 2. It can be seen that all species of *Acacia* tree having higher carbon content along with lower ash content which is making ATB a candidate precursor material to obtain AC having qualities comparable to commercially available AC in market. As shown in Table 1 the composition of various elements are well comparable with the reported values in the literature for other acacia tree branches (Saleem *et al*., 2017; Shivayogimath *et al*., 2014). A precursor material having high carbon content and lower sulphur and ash results in better quality AC (Macías-Pérez *et al*., 2007). The *Acacia* asak also having low sulphur content (0.02%) which may ranking it as an environment friendly precursor material to produce AC (Shahid *et*

Table 1. Results of elemental analysis and comparison with the other *Acacia* species reported in the literature.

Constituent (%)	*Acacia asak*	*Acacia seyal*	*Acacia nilotica*
C	52.7	51.3	48
K	0.93	1.82	--
Al	ND	0.17	--
N	0.42	0.33	0.4
H	5.3	5.8	6
Zn	0.01	0.01	--
S	0.02	0.03	--
P	0.1	0.09	--
O	41.5	32.9	44
Ash	4.7	5.9	5.8

ND: Not Detected; Saleem *et al*. (2017); Shivayogimath *et al*. (2014).

al., 2011). Therefore, ATB could be use as an appropriate precursor material for good quality AC production.

A comparison of results obtained from proximate and detailed analysis for all six types of produced ACs along with a commercially available AC (Filtrasorb® -400) presented in Table 2. in which also shows comparison between produced six ACs with two other species of *Acacia* trees (*Acacia seyal* and *Acacia nilotica*) reported in the literature.

Results show that all ACs prepared in the present study by three-steps-process utilizing six chemical activating agents mentioned earlier, posses high S_{BET} surface area, which is well comparable with the commercially available AC (Filtrasorb® -400). Among six produced ACs, obtained S_{BET} surface area is in the order of ATB-AC1> ATB-AC2> ATB-AC4> ATB-AC6> ATB-AC3> ATB-AC5. Therefore, ATB-AC1 and ATB-AC2 achieved surface area more than CAC (1037 and 992 m2/g respectively) as compared to other produced ACs. Similar trend in pore volume observed, which shows that AC produced from ATB using three-steps-process provides better carbonization and activation, which utilize H_3PO_4 and $ZnCl_2$ as chemical activating agent. Similar results were reported elsewhere when comparing the AC produced by single, two and three steps chemical activation method (Tran *et al*., 2017). The three-steps-process provides higher surface area which may be attributed to the hydrothermal treatment of precursor material produced hydrochar which facilitate the better penetration of activating agent H_3PO_4 and $ZnCl_2$ in the pore space, and results in relatively higher surface area during activation.

Results reported in Table 2 also showing that the obtained BET surface area of produced ACs are well comparable to the area obtained by researchers utilizing other species of *Acacia* tree branches; *Acacia seyal* and *Acacia nilotica*. Once comparing with the S_{BET} surface area of Filtrasorb® -400 (i.e 944 m^2/g) the surface areas of ATB-AC1 and ATB-AC2 are 9.85% and 5.1% higher than CAC respectively. Results of iodine number demonstrated similar behaviour.

Results of pore volume and iodine number showing that the properties of AC strongly depends on the type of preparation method and adsorbent pore volume depends on the type of activating agent utilized. Thus, three-steps-process seems to be more favorable method in the preparation of better AC and H_3PO_3, and $ZnCl_2$ are most suitable chemical activating agents among six studied agents. A similar conclusion has been drawn by other researchers (Wong *et al*., 2018; Tran *et al*., 2017). The ball-pan hardness test which reflects the resistance of an AC against degradation, measured and

Table 2. Comparison of characteristics of six produced ACs with commercial ACs and AC produced from other species of *Acacia* tree

Property	*Filtrasorb® 400	ATB-AC1	ATB-AC2	ATB-AC3	ATB-AC4	ATB-AC5	ATB-AC6	*Acacia seyal*	*Acacia nilotica*
Activation agent	--	H_3PO_4	$ZnCl_2$	H_2SO_4	K_2CO_3	NaOH	KOH	H_3PO_4	KOH
Ball-pan hardness	High	95	92	94	90	91	89	91	Low
Ash (%)	5-6	3.21	6.13	5.74	5.73	6.25	6.78	5.9	5.8
Bulk density (g/cc)	0.44	0.51	0.47	0.49	0.35	0.39	0.41	0.3	--
Moisture content (%)	--	2.9	3.21	4.17	4.6	4.08	3.35	4.2	4.1
Volatile matter	--	2.42	3.16	2.79	2.73	3.24	2.78	--	5.12
Fixed carbon	--	91.47	91.47	87.3	86.94	86.43	87.09	--	--
pH	6.2	6.7	6.9	6.4	7.6	7.8	7.3	6.5	7.0
S_{BET} (m^2/g)	944	1037	992	792.6	814.3	781.6	805.5	762	590
Pore volume (m^3/g)	0.7	5.26	5.07	4.82	5.1	4.76	4.91	4.92	4.4
Pore mean radius (mm)	1.48	10.14	10.22	12.16	12.52	12.18	12.19	12.91	14.91
Iodine number (mg/g)	1000	927	895	879	892	867	886	827	480

* Calgon carbon corporation, Pennsylvania, 15205 USA; (Saleem *et al*., 2017; Shivayogimath *et al*., 2014).

results show that all the produced ACs possess very good hardness and well suitable for liquid phase batch and continues flow separation processes.

Furthermore, a basic cost analysis conducted while considering the procurement cost of precursor material, chemicals used, power consumed and labor cost. It was found that the final cost of produced ACs ranging from $0.4 to $0.5 per Kg. Therefore, the AC produced by waste Acacia asak branches, which are available in abundance, obtained during tree pruning result in an economical means for producing AC as well as contribute in solid waste management and reduction.

Removal efficiency of ATB-ACs. Removal efficiency of ATB-ACs along with commercial AC Filtrasorb® -400 was evaluated in laboratory batch experiments in which produced and commercial ACs were suspended in 50 mg/L MB solution as mentioned before.

The temporal removal efficiency of ATB-ACs and Filtrasorb® -400is depicted in Fig. 1. It is evident from Fig. 1. that initially commercial AC removal is highest up to 50 min. as compared to all ATB-ACs however, after that, the removal efficiency of ATB-AC1 and ATB-AC2 becomes comparable to it. After about 50 min. of experimental run the improvement in the removal efficiency became insignificant for all the ACs. The final removal efficiencies of ACs achieved were 98.4%, 98.8%, 98.3%, 92.4%, 94.3%, 90.7% and 92.8% for CAC, ATB-AC1, ATB-AC2, ATB-AC3, ATB-AC4, ATB-AC5 and ATB-AC6 respectively. The high removal efficiency of ATB-AC1 and ATB-AC2 for MB dye could be attributed to the utilization of H_3PO_4, and $ZnCl_2$ as activating agent and three-steps-process which aids in the yield of high BET surface area and well developed porosity.

MB dye uptake capacity of ATB-AC. In this part of study the experimental runs were performed to compare the MB dye uptake capacity of all ATB-AC with commercial AC Filtrasorb® -400. The uptake capacity of Filtrasorb® -400 and ATB-AC are presented in Fig. 2. Results show that the adsorption capacity of ATB-AC1, ATB-AC2, ATB-AC4 and ATB-AC6 (271.8, 264.9, 259.3, and 252.1 mg MB/g AC respectively) are higher than the CAC (235.3 mg MB/g AC). It can be seen that the pore volume of ATB-AC3 and ATB-AC5 is higher than the pore volume of CAC (4.82, 4.76 and 0.7 m^3/g for ATB-AC3, ATB-AC5 and CAC respectively, as shown in Table 2), it means that the MB uptake capacity is not much depends on the pore volume and the controlling parameter could be the BET-Surface (S_{BET}) area. Results reported here is in contrast with the conclusion of study reported by Hussein *et al*. (2015), which showing the dependency of AC uptake capacity solely on the pore structure and volume. Variance in the studies could be attributed to the use of different raw material (date palm tree biomass) which may

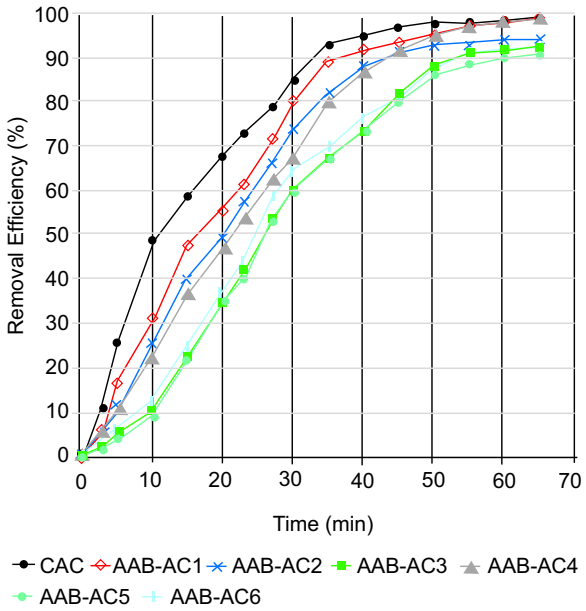

Fig. 1. Comparison of MB removal efficiency of produced ACs with CAC.

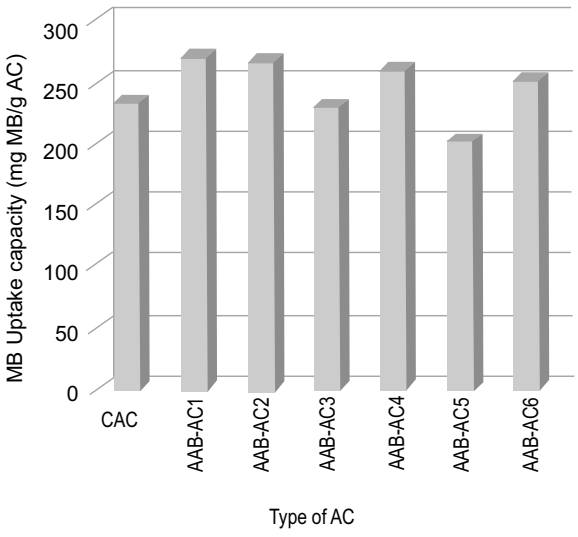

Fig. 2. Comparison of MB uptake capacity for ATB-ACs and CAC.

produce pore volume due to different pore structure. However, further study is warranted to investigate effect of various precursor material on pore volume, S_{BET} surface area and the uptake capacity.

Conclusions and Recommendations. Present study revealed that the *Acacia asak* tree branches available in Saudi Arabia as a waste material to dispose in cost effective and environment friendly way. Study show that ATB could be considered as an excellent raw material to produce valuable and good quality AC by three-steps-process utilizing chemical activating agents. Effects of various chemical activating agents evaluated by keeping all other production parameters constant and varing only the activating agents (H_3PO_4, $ZnCl_2$, H_2SO_4, K_2CO_3, NaOH and KOH) to provide a clear comparison. Following specific conclusions are drawn from the results of present study:

- Elemental analysis of precursor material revealed that the ATB having high carbon content (52.7%), low sulphur and ash content (0.02% and 4.7% respectively), thus ranking it as a suitable material for producing good quality and environment friendly AC.
- H_3PO_4 and $ZnCl_2$ are better chemical agents as compared to H_2SO_4, K_2CO_3, NaOH and KOH as produced AC possess high S_{BET} surface area and pore volume (S_{BET} surface area 1037 and 992 m^2/g respectively and pore volume 5.26 and 5.07 m^3/g respectively) as compared to CAC (Filtrasorb® - 400) having S_{BET} area 944 m^2/g and pore volume only 0.7 m^3/g.
- Temporal variation in removal efficiency of produced ACs with CAC investigated and found that the removal efficiency of CAC was high initially up to 30 min however, comparable removal efficiencies obtained after about 50 min of experimental runs (98.8% and 98.3% as compared to 98.4% for CAC).
- High hardness of produced ACs (Ball-pan hardness # 89-95) suggests as suitable AC for batch-mixed as well as continues flow wastewater treatment systems.
- Produced ACs show high MB uptake capacity 235.3, 271.8, 264.9, 229.7, 259.3, 201.6 and 252.1 mg MB/g AC for CAC, ATB-AC1, ATB-AC2, ATB-AC3, ATB-AC4, ATB-AC5 and ATB-AC6 respectively which may be attributed to high S_{BET} surface area and pore volume produced during three-steps-process utilizing chemical activating agents.
- Among six produced ACs, ATB-AC1 and ATB-AC2 and ATB-AC6 demonstrated higher MB uptake capacity (produced by H_3PO_4, $ZnCl_2$ and KOH respectively).
- Cost analysis for the production of AC shows that ATB can produce good quality AC and cost is between $0.4 to $0.5/ Kg, which is making it economically feasible material as well.

Therefore, if considering the availability of low cost waste material and low energy consumption, in producing AC (by three-steps carbonization and activation method) ATB-AC could be a suitable candidate material for producing economical and well comparable AC (with commercially available ACs). Furthermore, research is warranted to test different chemical activating agents for their ability to produce AC having high S_{BET} surface area and pore volume. In addition to that, further investigations are needed to evaluate other parameters including hydrolysis and activation time, temperature, impregnation ratio and other methods such as microwave heating.

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